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The Beyşehir–Hoyran–Hadim Nappes: genesis and emplacement of Mesozoic marginal and oceanic units of the northern Neotethys in southern Turkey

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Abstract: The Beyşehir–Hoyran–Hadim Nappes crop out over 700 km from NW to SE. Above a regionally autochthonous Tauride carbonate platform the Beyşehir–Hoyran Nappes begin with a thrust sheet (*c*. 400 m) of mainly redeposited carbonates, quartzose sandstones and mudstones of Mid–Late Triassic age, interpreted as a proximal slope–base-of-slope succession. Above is a thrust sheet (*c*. 1 km) of Middle–Upper Triassic intermediate–acidic extrusive rocks, volcaniclastic rocks and minor pelagic carbonates, interpreted as a continental rift. Thin (<100 m) Upper Triassic–Upper Cretaceous pelagic carbonate and radiolarian chert lie depositionally above. The uppermost thrust sheet comprises broken formation and mélange, including Jurassic shallow-water carbonate, radiolarian chert and Upper Cretaceous pelagic limestone. Zones of tectonic–sedimentary mélange separate higher units. The Beyşehir–Hoyran Nappes document Triassic rifting and Jurassic–Cretaceous passive margin subsidence bordering the Northern Neotethys. A harzburgitic ophiolite probably formed above a north-dipping subduction zone within the ocean basin. The ophiolite was emplaced southwards onto the northern margin of the Tauride platform in latest Cretaceous time. The nappe pile and underlying platform (Hadim Nappe) were thrust further south in Late Eocene time. Assuming in-sequence thrusting, the Beyşehir–Hoyran Nappes restore to a location north of a Neotethyan spreading axis. More probably, they originated near the south margin of the Northern Neotethys, but reached their position by out-of-sequence thrusting. Formation within a southerly strand of the Northern Neotethys (Inner Tauride ocean) is more probable than within the main Northern Neotethys further north.

Keywords: Turkey, Neotethys, tectonics, thrust sheets, orogeny.

Many emplaced continental margins are structurally complex and have experienced multiple deformation events. Attempts to restore such margins depend critically on whether in-sequence ('piggy-back') thrusting can be assumed. For example, in the Tethyan regions, most reconstructions have assumed in-sequence thrusting (e.g. Othris, Greece; Smith *et al*. 1979; Pindos, Greece; Fleurry 1980; Degnan & Robertson 1998; Antalya, SW Turkey; Robertson 1993). However, out-of-sequence thrusting has been shown to play a role in some emplaced continental margins (e.g. Oman; Searle *et al*. 1990). Here, we consider the example of the regionally extensive Mesozoic Beyşehir–Hoyran Nappes within the central Taurus Mountains, southern Turkey (Fig. 1). We reconstruct their tectonic evolution and palaeogeography based on new sedimentological, structural and igneous geochemical data, combined with integration of existing tectonostratigraphical information. We consider alternative in-sequence v. out-of-sequence thrust reconstructions with implications for comparable emplaced contintental margins elsewhere.

Since their discovery byBlumenthal (1947, 1951, 1956, 1960–1963), the regional tectonostratigraphy of the Beyşehir–Hoyran Nappes was established by Monod (1977) and byÖzgül (1976, 1997). In addition, various parts of the Beyşehir–Hoyran Nappes and related relatively autochthonous units were studied by a number of workers, including Haude (1969), Koçyiğit (1976), Gutnic (1977), Gutnic *et al*. (1968, 1979), Gökdeniz (1981) and Demirkol (1984). More recently, part of the area was remapped by the Turkish Maden Tetkik ve Arama (Maden Tektik ve Arama Genel Müdürlü ğü 1997; Şenel *et al*. 1998).

The Beyşehir–Hoyran Nappes include Mesozoic carbonate platform, deep-sea and ophiolitic units that were seen as part of a vast unit (Bozkir Nappes; Özgül & Arpat 1973), including the Lycian Nappes to the west, that were thrust from a Northern Neotethyan ocean basin onto the Anatolide–Tauride carbonate platform to the south in latest Cretaceous time (Şengör & Yılmaz 1981; Tekeli 1981; Robertson & Dixon 1984; Dercourt *et al*. 1986, 1992; Stampfli 2000).

Below, we outline the tectonostratigraphy and age relations of units within four representative areas, from east to west, and demonstrate a regional coherence over *c*. 700 km, allowing overall tectonic reconstructions (Figs. 1 and 2).

Regional setting

We summarize each unit from NW to SE below.

Dinar area

The Dinar Units (Fig. 1) were previously correlated with the Lycian Nappes (Özgül & Arpat 1973; Gutnic 1977; Gutnic *et al*. 1979), but are grouped here with the Beyşehir–Hoyran–Hadim Nappes in view of similarities in tectonostratigraphy and timing of emplacement. The most westerly, volumetrically smallest, outcrop area of the nappes, known as the Hoyran Nappes of the Pisidian Taurus (Gutnic *et al*. 1979), comprise four main thrust sheets (Figs. 2 and 3) above an autochthon (Sandikli Series). The latter comprises Precambrian and Palaeozoic 'basement' (Gutnic 1977; Göncüoğlu & Kozlu 2000) overlain by Lower Jurassic siliciclastic sedimentary rocks, which are in turn unconformably overlain by Middle Jurassic to Upper Cretaceous platform carbonates (Fig. 4a). At the top, neritic carbonates pass into Maastrichtian pink pelagic limestones, including the planktonic foraminifera *Globotruncana stuarti*, *G. caliciformis*, *G. arca*, *G.*

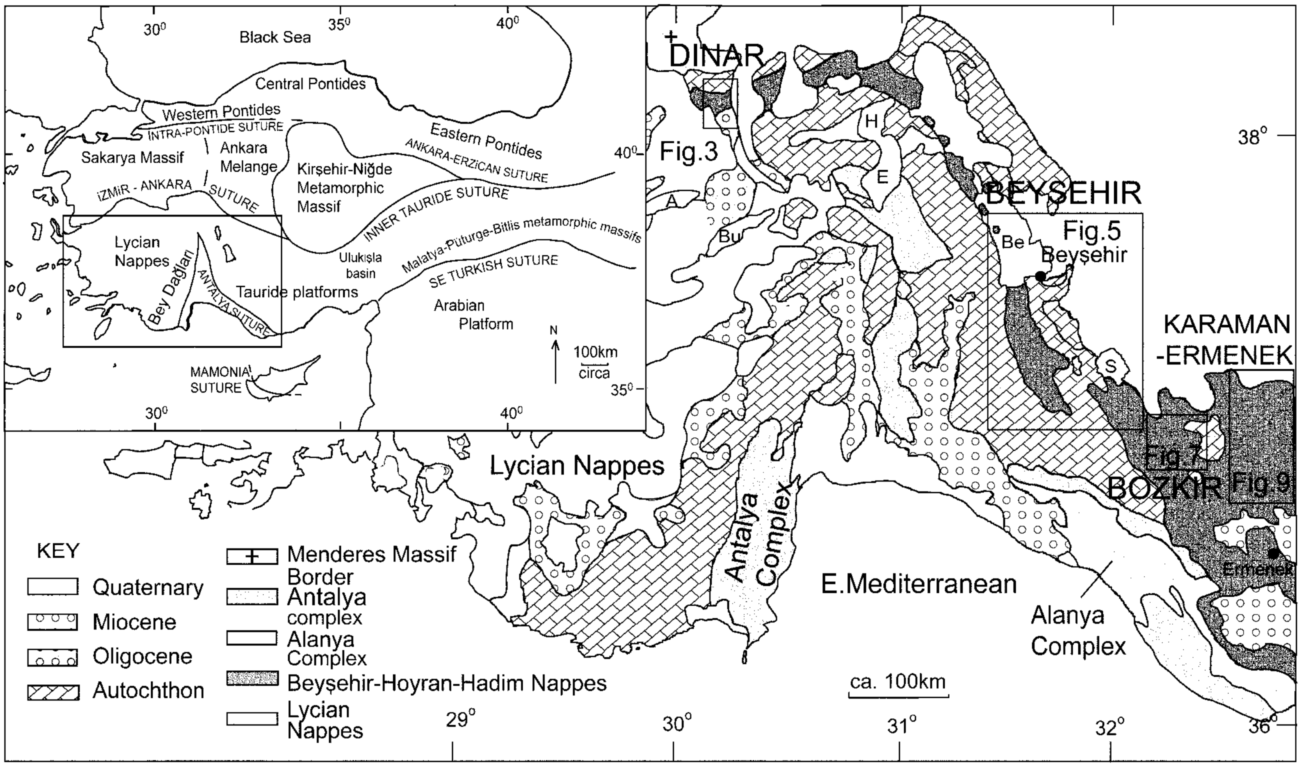

Fig. 1. Tectonostratigraphic map of SW Turkey (after Gutnic *et al.* 1979). A, Lake Açı; Bu, Lake Burdur; H, Lake Hoyran; E, Lake Eğirdir; Be, Lake Beyşehir; S: Lake Suğla. Inset: main tectonic subdivisions of Turkey.

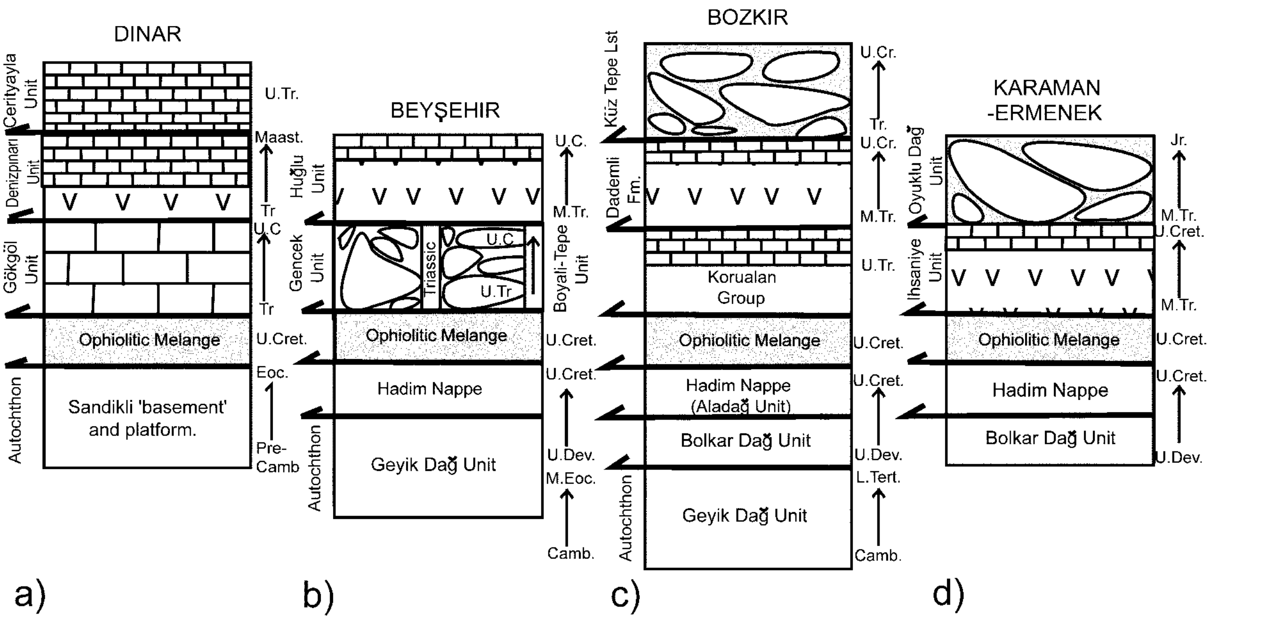

Fig. 2. Tectonostratigraphic correlation of the Beyşehir–Hoyran–Hadim Nappes. (Note the similarities in tectonostratigraphy over *c.* 300 km from NW to SE.) The Hadim Nappe (not present in the Dinar area) is at the base, followed by the Upper Cretaceous Ophiolitic Mélange (including ophiolite slices), in turn overlain by up to five distinct thrust sheets of Mid-Triassic to Late Cretaceous age.

contusa, *G. helvetica* and *G. linnei* (Gutnic 1977). Depositionally above are siliciclastic sedimentary rocks, debris flow deposits and slumps containing Early to Mid-Eocene large foraminifera (e.g. *Nummulites*) (Gutnic 1977).

The Hoyran Nappes (Fig. 2a) begin with Ophiolitic Mélange (Fig. 3). Above, the Gökgöl Unit (<500 m thick) comprises overturned Triassic–Upper Lias neritic dolomite and limestone, depositionally overlain by a Toarcian to Upper Cretaceous pelagic succession (Fig. 4b). Above this, the Denizpınarı Unit (<900 m thick) comprises sheared lavas interbedded with, and

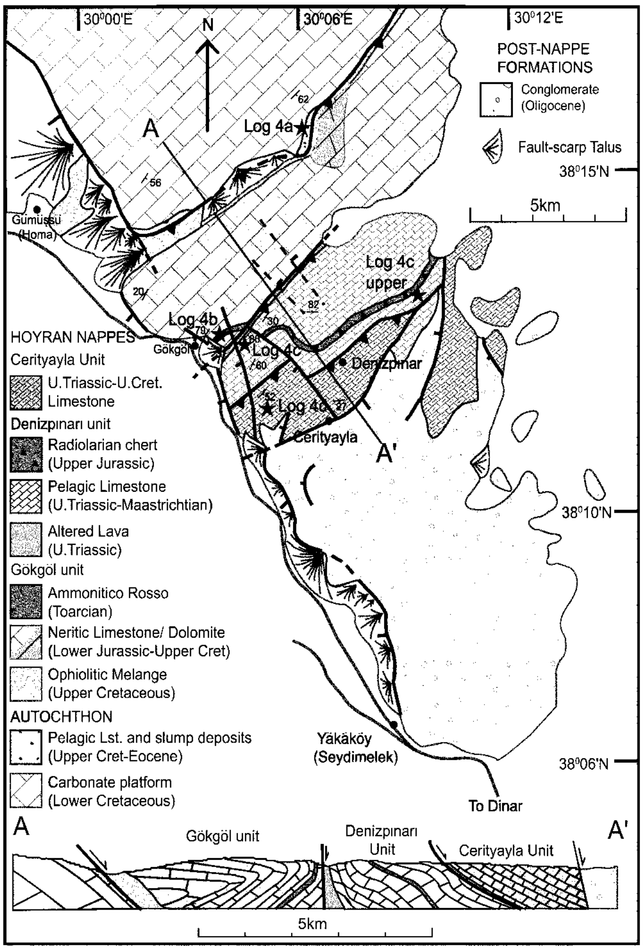

Fig. 3. Geological map and cross-section of the Beyşehir–Hoyran Nappes to the north of Dinar (modified from Gutnic 1977).

overlain by, Triassic pelagic limestones, followed by a pelagic sequence including Upper Jurassic radiolarian chert and Upper Cretaceous pelagic limestones, rich in *Globotruncana* sp. (Fig. 4c; Gutnic 1977). Finally, the third nappe, the Cerityayla Unit (*c.* 400 m), consists mainly of Triassic pelagic limestones (Fig. 4d).

Beyşehir area

Lake Beyşehir is the type area owing to excellent exposure and clear structural relationships (Monod 1977; Figs. 1, 2 and 5). The Mesozoic autochthonous succession (Beyşehir Series, Seydisehir Series and Akseki platform) is similar to the Sandikli Series of the Dinar area. Both exhibit a Palaeozoic basement of regionally similar units (Dean & Özgül 1994) unconformably overlain by Upper Triassic–Lower Jurassic siliciclastic rocks and Mesozoic–Lower Eocene platform carbonates, culminating in Mid-Eocene siliciclastic turbidites and debris flow deposits (i.e. Geyik Dağ Unit; Özgül 1976). Stratigraphic gaps, marked by basal conglomerates and bauxite horizons, commonly occur in the Cenomanian sequence in northeasterly areas of the central Taurides (Özgül 1976; Monod 1977).

Four main thrust sheets are present above the local autochthon (Fig. 2b). The lowest, the Hadim Nappe in the SW (Fig. 6a), begins with Upper Devonian shales, sandstones and quartzites with carbonate intercalations, overlain by Carboniferous shales, limestones and quartzites. The Permian period is represented by thick (>1500 m) shallow-water limestones (Özgül 1976; Monod 1977). The succession passes into Lower Triassic limestone and shale, overlain by Middle Triassic siliciclastic rocks, then uppermost Triassic red sandstone and conglomerate. The red clastic interval is correlated with similar facies in the autochthon (e.g. Çayir Formation and Üzümdere Formation; Monod & Akay 1984). The Jurassic–Upper Cretaceous sequence of the Hadim Nappe (Çamlık Unit, Fig. 6a) is characterized by platform carbonates (Özgül 1976; Monod 1977).

The overlying Upper Cretaceous Ophiolitic Mélange (Fig. 2) includes amphibolite interpreted as a metamorphic sole (e.g west of Gencek village), and a dismembered ophiolite, mainly serpentinized harzburgite and dunite. Slices of Permian fusulinid limestone occur locally beneath the ophiolite (Monod 1977). The Ophiolitic Mélange is overthrust by the Gencek Unit (Figs. 2 and 6b), consisting of Triassic massive neritic limestone, including the large bivalve *Megalodon*. Further north, at a similar structural level, a more complete succession is known as the Boyali-Tepe Unit (Figs. 2 and 6c). This consists of well-bedded Upper Triassic neritic limestone, depositionally overlain by a Lower Jurassic to Upper Cretaceous pelagic sequence, including Toarcian to Mid-Jurassic Ammonitico Rosso and Upper Cretaceous *Globotruncana*-bearing pelagic limestone (Monod 1977). The succession ends with a polygenetic debris flow deposit, with ophiolite-derived clasts. This unit can be traced tens of kilometres NW along the north shore of Lake Beyşehir. Both the Gencek and the Boyali-Tepe Units are fragmented and form up to kilometre-sized blocks and a dismembered thrust sheet set in a sandy matrix ('Wildflysch'). The matrix includes radiolarian chert, neritic limestone, pelagic limestone, calcarenite and detrital quartz.

Above is the Huğlu Unit (Fig. 6d), which comprises a Middle Triassic volcanogenic sequence of interbedded green siliceous lava, fine-grained volcaniclastic sandstone–siltstone and green ribbon chert ('tuffite'), also minor redeposited limestone and coarse-grained volcaniclastic sediment (particularly near the base). Permian fusulinid limestone is found as rare lithic fragments within basalt lava flows (Monod 1977). Analyses of lava samples reveal a variable SiO_2 content (49.9–69.9%; Table 1). Above follows an intact succession of Upper Triassic–Upper Cretaceous pelagic carbonates (Monod 1977).

Bozkir area

Above the regional autochthon (Geyik Dağ; Özgül 1976), are the Bolkar Dağ Unit and the Hadim Nappe (Aladağ Unit; Fig. 7) in a structurally low position, followed by the Upper Cretaceous Ophiolitic Mélange and a dismembered ophiolite (Özgül 1997). Above, the Upper Triassic Korualan Group (*c.* 200 m thick) begins with *c.* 40 m of dolomite, followed by *c.* 100 m of turbiditic siltstone, sandstone and redeposited limestone, culminating in an undated (recrystallized) pelagic limestone and chert sequence (Fig. 8a).

The middle thrust sheet (Fig. 8b) is a Middle–Upper Triassic volcanogenic succession (Dedemli Formation), with an Upper Triassic–Upper Cretaceous pelagic carbonate cover (Mahmut Tepe Formation; Özgül 1997). The MiddleTriassic succession is dominated by basic–intermediate composition lava, green volcaniclastic siltstone and interbedded pelagic limestone of Carnian age (Tekin 1999). The uppermost unit (Fig. 8c) is a dismembered succession of Triassic–Lower Jurassic neritic carbonates overlain by Toarcian–Upper Cretaceous pelagic carbonates and radiolarian chert, locally termed the Küz Tepe, Asar Tepe and Soğucak Formations (Özgül 1997).

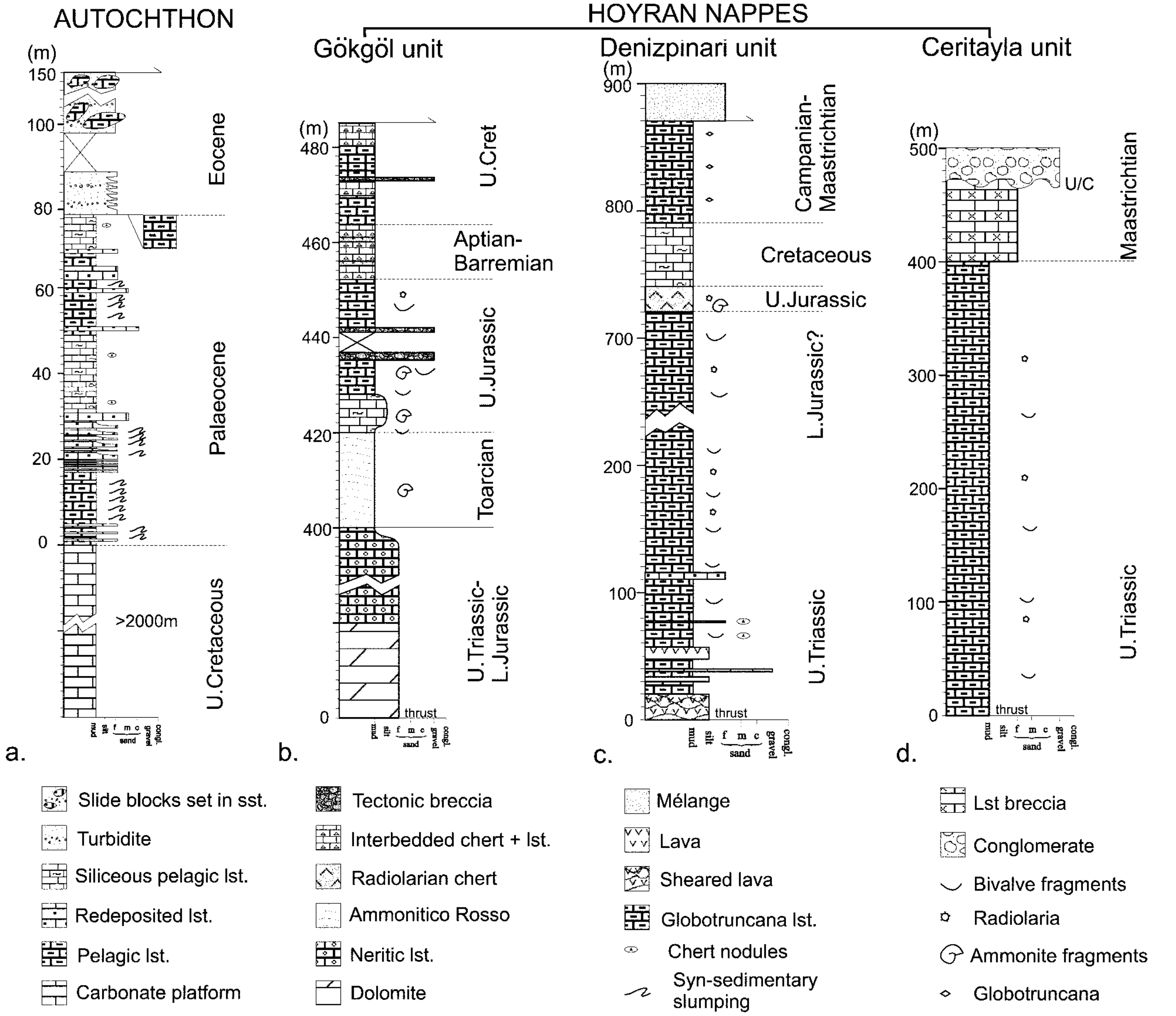

Fig. 4. Measured sedimentary logs of the Beyşehir–Hoyran units in the Dinar area. (See Fig. 3 for location of logs.)

Ermenek–Karaman area

The easternmost area of the Beyşehir–Hoyran–Hadim Nappes covers *c.* 100 km (Figs. 9 and 10). The lowest exposed unit is the relatively autochthonous Mesozoic Bolkar Dağ Unit, which is overlain by Ophiolitic Mélange and higher units. The Hadim Nappe is exposed as a separate unit further south. Ophiolite (other than mélange) crops out only south of Ermenek, outside the main study area. The structurally higher, internally imbricated, Ihsaniye Unit exposed in both the Ermenek and Karaman areas (Fig. 11a and b) begins with Triassic siliciclastic turbidites (locally with plant remains), basic–intermediate composition lava and thin-bedded volcaniclastic sediment, all overlain by a thick succession (>200 m) of fine-grained, green volcaniclastic sediment (Gökdeniz 1981). An Upper Triassic–Upper Cretaceous pelagic limestone sequence follows, with a thick (>80 m) tectonically imbricated radiolarian chert horizon. The overlying Oyuklu Dağ Unit comprises Triassic to Jurassic massive neritic carbonates (Fig. 11c). Further north, in the Karaman area (Fig. 9), the Bolkar Dağ Unit culminates in a thick monomict limestone breccia and is tectonically overlain by heterogeneous kilometre-sized blocks and disrupted sheets of Ihsaniye and Oyuklu Dağ unit-type lithologies in a sheared ophiolite-derived matrix.

Regional interpretation

Regional autochthon (Geyik Dağ Unit)

The Upper Precambrian to Cambrian Sandikli Series is interpreted as Pan-African continental basement (Dean & Özgül 1994; Göncüoğlu 2001), overlain by Upper Triassic shales and siliciclastic sediments deposited on a rifted fragment of the north Gondwana shelf. Overlying shallow-water carbonates of Mid–Late Triassic age record a subsiding Bahama-type carbonate platform adjacent to Neotethys. Fluvial to shallow-marine clastic sediments (Çayir Formation) of latest Triassic age record fault-related uplift and erosion of the underlying basement (Monod & Akay 1984), possibly a compressional effect related to the final emplacement of the Karakaya Complex in the Pontides further north (Robertson & Pickett 2000). Carbonates and passive margin subsidence dominated the remainder of Mesozoic time,

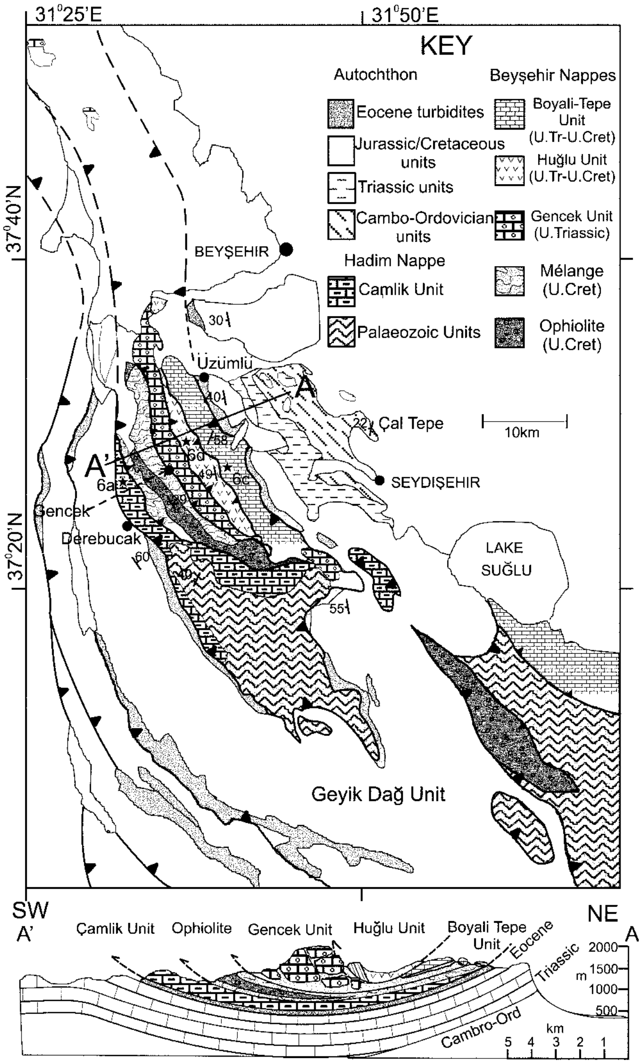

Fig. 5. Geological map and cross-section of the Beyşehir–Hoyran Nappes in the Beyşehir area (modified from Monod 1977).

with a switch to deeper pelagic carbonate deposition in Late Cretaceous time. The exposed autochthon remained largely unaffected by regional events, including Late Cretaceous ophiolite emplacement. However, a switch to pelagic carbonate and deepening in Late Cretaceous time was possibly tectonically controlled. During Late Eocene time the platform subsided as a flexural foredeep ahead of the emplacement of the Beyşehir–Hoyran–Hadim Nappes.

Hadim Nappe

Where present, the Hadim Nappe exhibits a similar Palaeozoic–Cretaceous succession to the autochthon. The Upper Devonian–Upper Cretaceous succession records a shallow-marine carbonate platform setting, punctuated by emergence and erosion in latest Triassic time, coinciding with the deposition of shallow-marine to fluvial clastic sediments (Çayir Formation; Monod & Akay 1984). However, the Geyik Dağ Autochthon and Hadim Nappe differ in the Upper Cretaceous units as Ophiolitic Mélange is present on the latter, showing that the Hadim Nappe was overthrust by oceanic crust, which, however, did not reach the Geyik Dağ further south. The Hadim Nappe and Bolkar Dağ Unit are seen as facies variants within the original Tauride carbonate platform (Geyik Dağ), with the Bolkar Dağ Unit, in particular, showing a relatively thin and variable succession.

Ophiolitic Mélange

Ophiolitic Mélange is always at the same relative structural position, i.e. above the Hadim Nappe (where present), but below the Upper Nappes (Fig. 2). Ophiolitic Mélange is also found at structurally higher levels in both the Bozkir and northern Ermenek–Karaman areas, usually as the matrix of dismembered units ('broken formation'). The mélange is dominated by a chaotic admixture of neritic and pelagic limestone, radiolarian chert, basic volcanic rocks, serpentinite, volcaniclastic sediments (including debris flow deposits), gabbro and amphibolite, set in a sheared, incompetent matrix of ophiolite-derived sandstone and mudstone. In the Beyşehir region, kilometre-sized blocks of fusulinid-bearing Permian limestone occur directly beneath the ophiolite (Monod 1977). A crude layering is present, marked by different compositions of blocks in the Beyşehir area. The mélange matrix is dated to Late Cretaceous (Maastrichtian) time based on planktonic foraminifera, including *Globotruncana arca,* from blocks of pink pelagic limestone in the Bozkir area (Özgül 1997).

Whole-rock XRF analysis of basaltic clasts from the Ophiolitic Mélange in the Beyşehir and Dinar areas reveals the presence of two compositional groups (Fig. 12a and b; Table 1). One is relatively enriched in the high field strength elements (HFSE) compared with normal mid-ocean ridge basalt (N-MORB) (Fig. 12b) and shows within-plate affinities in tectonic discrimination diagrams (Fig. 13). The second shows minor depletion in HFSE, with marked Nb depletion (Fig. 12a), suggestive of formation in a subduction-influenced setting (Pearce *et al.* 1984).

The dominantly deep-sea nature of the mélange matrix and the similarity of deformation fabrics to modern oceanic forearc complexes (e.g. the Barbados arc; Mascle & Moore 1990) suggest that the mélange is a subduction–accretion complex. The basaltic blocks within the mélange are interpreted as accreted Tethyan oceanic crust erupted at both oceanic ridge (MORB–supra-subduction zone (SSZ)) and seamount settings (within-plate affinities).

The accretionary prism included relatively near-margin units that were incorporated during initial Maastrichtian tectonic emplacement over the continental margin (i.e. Triassic rift-related neritic limestone), and pre-rift Permian fusulinid limestone in the Beyşehir area.

No mélange lithologies younger than Late Cretaceous (Maastrichtian) time are known in the mélange in the central and eastern areas (Bozkir–Ermenek), suggesting that the accretion had ended by this time.

Ophiolite

Large coherent slices of serpentinized peridotite occur within the Ophiolitic Mélange in several areas, e.g. to the north and south of Lake Beyşehir, Bozkir (Dipsiz Göl) and to the south of the Ermenek area. At present, these are dated only to pre-Maastrichtian time by the age of the mélange matrix and the metamorphic sole (Ö. F. Çelik, pers. comm.). An amphibolite-facies metamorphic sole locally occurs beneath the peridotite and is well exposed north of Lake Beyşehir (Elitok 2000). Greenschist- and amphibolite-facies rocks, probably also fragments of meta-

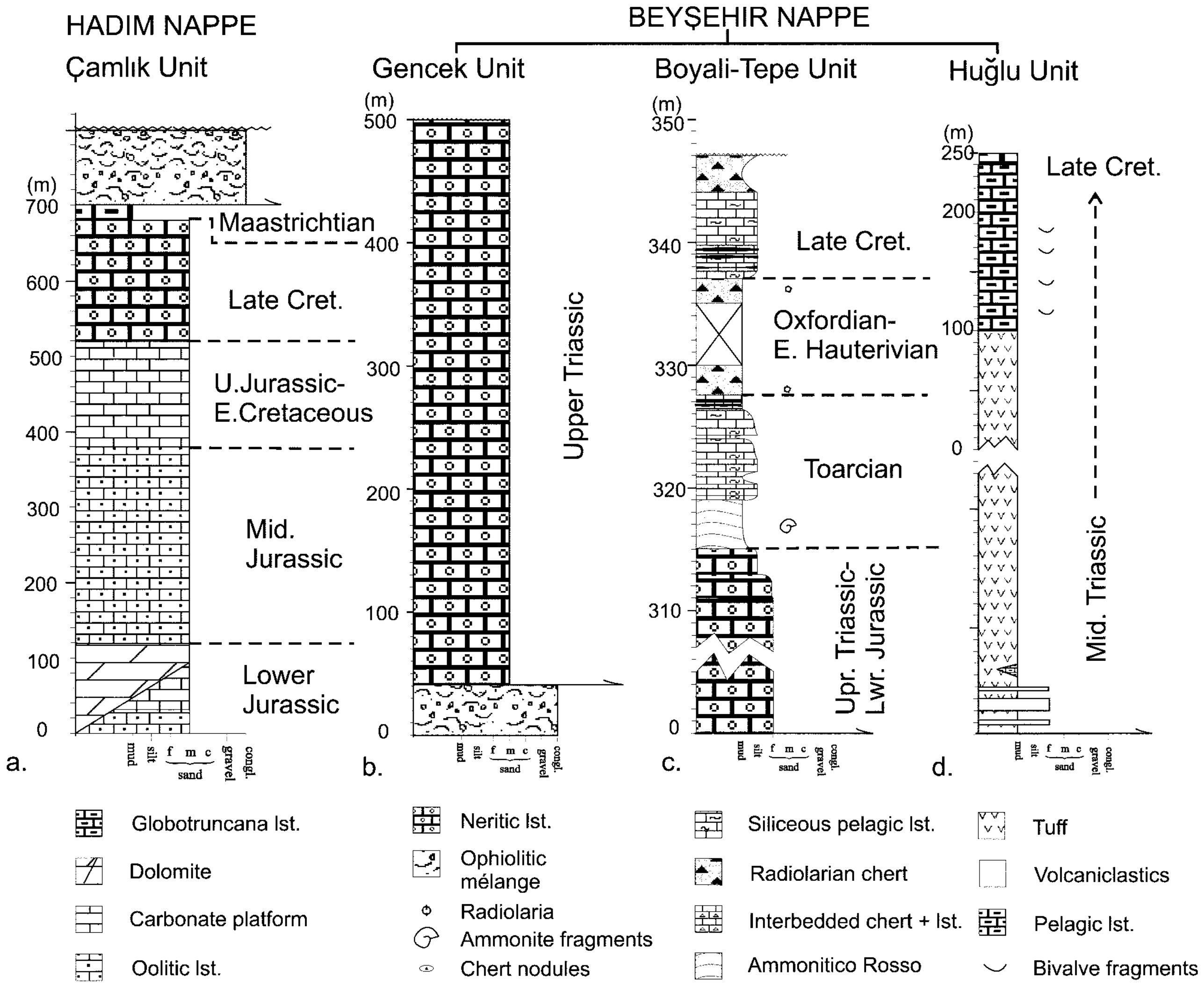

Fig. 6. Measured sedimentary logs of the Beyşehir–Hoyran units in the Beyşehir area. (See Fig. 5 for location of logs 6a and 6b adapted from Monod (1977).)

morphic sole, occur locally as detached blocks within the Ophiolitic Mélange (Monod 1977).

The peridotite is dominantly serpentinized harzburgite, ranging from fresh to 70% altered, with minor pyroxenite, dunite and chromite pods (Elitok 2000). Dolerite dykes that cut the peridotite show chilled margins and local metasomatic calcic alteration.

Whole-rock XRF analysis of relatively unaltered peridotite (Fig. 14a) reveals Cr and Ti contents comparable with inferred supra-subduction zone-type (SSZ) ophiolites (Pearce *et al.* 1984). Analysis of chrome spinel grains, using an electron microprobe, confirms enrichment in Cr relative to Mg (Fig. 14b), as in present-day island-arc rocks and inferred SSZ-type ophiolites (e.g. Oman ophiolite, Dick & Bullen 1984). Peridotite from north of Lake Beyşehir, when normalized to N-MORB, shows enrichment in large ion lithophile elements (LILE) relative to HFSE. Such enrichment is attributed to mantle wedge metasomatism by LILE-enriched hydrous fluids, derived from subducted oceanic crust in an SSZ setting. Whole-rock analysis of dolerite dykes cutting the peridotite reveals an immobile trace-element composition similar to SSZ-type basalt (Fig. 12c).

Özgül (1984) envisaged the Dipsiz Göl ophiolite as formed by rifting of the Tauride carbonate platform in Late Cretaceous time, for which we have not found supporting evidence. Instead, the available geochemical data from the peridotite thrust sheets are consistent with genesis in an intra-oceanic SSZ setting, as for other 'depleted' Neotethyan peridotites (e.g. Oman, Troodos, Pearce *et al.* 1984; Lycian Peridotite thrust sheet, Collins & Robertson 1998). Alternative models for SSZ ophiolites include collapsed spreading ridges, incipient subduction zones and fore-arc–back-arc settings (Dilek *et al.* 1998; Robertson 2002). Thus the chemical data must be treated with caution in tectonic synthesis.

Triassic slope facies: Korualan Group

This unit, known only in the Bozkir area (Figs. 2 and 8a) at the base of the Beyşehir Nappes, is interpreted as a Triassic slope to base-of-slope unit adjacent to a carbonate platform. Pelagic conditions were established by latest Triassic time. The Korualan Group was possibly tectonically cut out in other areas during emplacement.

Table 1. *Representative whole-rock geochemical analyses of volcanic rocks from the Beyşehir–Hoyran Nappes*

	Dinar area: basaltic clasts in mélange					Beyşehir area: basaltic clasts in mélange				Beyşehir area: volcanic extrusive rocks (Huğlu Unit)			
Sample:	TA 257	TA 258	TA 259	TA 260	TA 251	TA 227	TA 228	TA 229	TA 240	TA 118	TA 282	TA 283	TA 286
SiO	50.36	58.31	54.99	55.55	59.88	51.35	51.57	51.49	52.76	68.74	64.55	69.23	69.92
AlO	15.53	14.61	15.35	15.64	14.79	15.48	15.21	15.35	16.36	9.83	17.78	15.60	13.71
FeO	10.37	8.87	8.39	9.53	11.90	9.16	9.04	9.08	11.36	2.00	4.08	3.34	3.58
MgO	6.83	5.36	5.21	5.51	4.54	7.58	7.47	7.78	5.52	0.55	2.30	1.75	1.69
CaO	9.78	5.69	7.88	6.32	3.86	12.63	12.55	12.45	9.49	9.72	0.78	0.55	0.41
NaO	3.60	6.33	5.91	6.16	5.02	2.94	3.07	3.00	2.96	0.35	6.26	4.47	0.11
TiO	1.61	0.73	1.07	1.11	1.45	0.84	0.82	0.83	1.44	0.26	0.27	0.21	0.25
MnO	0.16	0.17	0.13	0.16	0.14	0.16	0.16	0.16	0.19	0.15	0.13	0.12	0.10
PO	0.17	0.06	0.10	0.11	0.14	0.07	0.08	0.07	0.12	0.06	0.06	0.04	0.06
LOI (%)	2.74	2.76	2.66	2.55	4.14	2.45	2.45	2.64	4.11	7.02	4.12	3.38	1.61
Total	99.52	100.33	99.35	100.17	100.82	104.34	100.06	100.36	100.48	99.01	100.67	100.47	100.1
Nb	4.6	0.6	2.0	1.7	1.5	0.9	0.9	0.7	1.1	12	31	27	12
Zr	114	33	60	61	97	48	51	47	85	181	270	239	161
Y	33	19	25	23	37	21	23	20	31	27	37	32	33
Sr	238	270	625	522	74	109	85	96	332	44	34	25	23
Rb	21	2.1	2.7	0.6	0.5	2.6	1.5	2.5	4.4	136	119	118	196
La	6.4	0.8	4.0	4.0	2.9	1.7	3.1	3.6	3.6	36	36	31	26
Ce	13	7	10	9	9	7	6	4	9	66	80	71	52
Nd	13	6	10	9	10	9	7	7	12	27	33	29	25
Zn	92	50	71	79	31	69	68	67	84	42	112	84	113
Cu	90	6	65	60	6	83	83	81	57	14	16	8	24
Ni	85	36	52	49	15	78	92	96	36	5	6	4	6
Cr	311	59	105	83	14.7	189	206	215	50	10	12	12	13
V	303	254	301	277	263	280	265	272	359	10	35	20	26
Ba	51	50	97	41	22	81	66	54	26	239	237	301	360
Sc	44	40	40	42	34	47	46	46	39	1	5	2	5

Oxides are in weight percent and trace elements in parts per million. LOI, loss on ignition. Analytical methods and precisions have been given by Fitton *et al*. (1998).

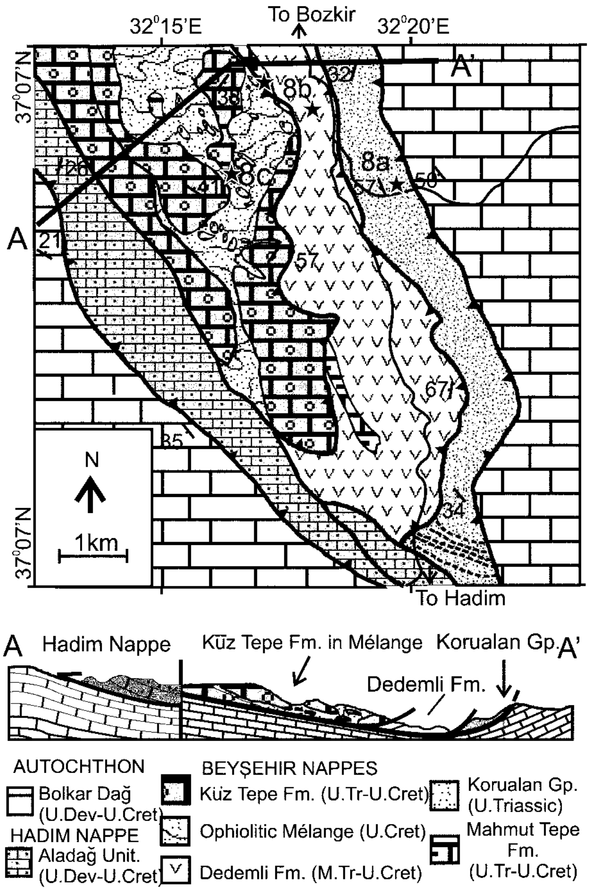

Fig. 7. Geological map and cross-section of the Beyşehir–Hoyran Nappes to the south of Bozkir.

Triassic volcanogenic rift unit and pelagic cover: Huğlu-type units

This tectonic unit is at a structurally lower position in the Bozkir and Ermenek–Karaman areas than in the Beyşehir area (Fig. 2). The lower, siliciclastic turbidites (e.g. Ermenek area) are indicative of a basinal setting within a continental rift that was inundated by volcanic rocks during Late Triassic time. The intermediate–acidic nature of the volcanic rocks may reflect melting of underlying continental crust undergoing low extension. The rifting was followed by post-rift subsidence and pelagic carbonate deposition at, or near, the calcite compensation depth (CCD) until Late Cretaceous time. Radiolarian chert accumulated in the more basinal areas (e.g. Ermenek–Karaman).

Triassic neritic carbonate and condensed pelagic cover: Boyali Tepe-type units

We interpret these successions as a more distal, Triassic carbonate platform removed from a continental source, as shown by the absence of siliciclastic sediment. Later, in Toarcian time, the carbonate platform was overlain by deeper-water Ammonitico Rosso condensed pelagic carbonates. Ribbon radiolarites then accumulated in Late Jurassic to Early Cretaceous time (T. Danelian, pers. comm.), followed by Late Cretaceous pelagic carbonates. Initial subduction–accretion gave rise to mélange and broken formation, including ophiolite-derived clastic sediments and material redeposited from underlying successions (chert breccia) set in a matrix including Maastrichtian pelagic carbonate.

Deformation phases

Initial compression took place in latest Cretaceous time, associated with emplacement of the ophiolite. This was dismembered and emplaced above an inferred accretionary prism, represented by the Ophiolitic Mélange, in Maastrichtian time. The structurally higher volcanogenic and neritic units were also tectonically assembled in latest Cretaceous time. The oceanic crust was emplaced onto the submerged Hadim, Bolkar and Sandikli platform units, whereas the Geyik Dağ platform was still well to the south and escaped this emplacement.

A second phase of emplacement was marked by collapse of the Taurus autochthon (Geyik Dağ) as a foredeep, accumulating Lower–Middle Eocene siliciclastic turbidites and then debris flows, finally overthrust by the Hadim Nappe (where present) and higher units. The Geyik Dağ is internally imbricated with ‘corridors’ of Middle Eocene siliciclastic turbidites underlying individual thrust imbricates (Özgül 1976; Monod 1977). The provenance of the siliciclastic sediment was probably from the basement of the overriding Hadim Nappe. Where the Hadim Nappe is absent in the west (Dinar area) the foredeep at the top of the Sandikli autochthonous carbonate platform succession contains Eocene large foraminifera (*Nummulites*), siliciclastic turbidites, debris flows and slumps (Fig. 4a).

Kinematic evidence

Kinematic data from shear zones between the thrust sheets were measured to infer the direction of emplacement. The base of the thrust sheets is well exposed SW of the Beyşehir area. A roadside cutting and quarry north of Derebucak (Fig. 5) reveals an extensive basal shear zone, *c.* 20 m thick, developed in coarse, heterogeneous debris flow deposits derived from the overriding thrust sheets. Brittle-shear fabrics (e.g. thrust-horse geometry, slickensides) indicate a top-to-the-SW sense of movement. Poles to the shear fabrics and slickenline data, when plotted on stereographic projections, indicate vergence to the SW with some scatter mainly to the south (Fig. 15a). Fold data from units within the nappes as a whole suggest a more westerly vergence, but are consistent with overall tectonic transport to the SW (Fig. 15a). In addition, brittle-shear indicators (i.e. slickenlines) and fold vergences from units within the thrust sheets in the Ermenek area (Fig. 15b) indicate a southwesterly transport direction.

Regional palaeomagnetic data suggest that the western area (at least) has undergone post-Eocene 40° clockwise rotation as part of the eastern limb of the Isparta Angle (Kissel *et al.* 1993; Tatar *et al.* 2000). Taking this into account, an overall southerly transport direction for the nappes is implied. The minimum displacement is from the northern edge of the platform to the present outcrop, *c.* 150 km.

Discussion of regional palaeogeography

The Beyşehir–Hoyran–Hadim Nappes can be restored to several alternative positions within the Northern Neotethys (Fig. 17) assuming either in-sequence (Fig. 16a) or out-of-sequence thrusting (Fig. 16b).

In Fig. 17a the Geyik Dağ, Sandikli Unit, Bolkar Dağ and Hadim Nappe formed an east–west-trending southerly continental margin. The Kirşehir–Niğde massif formed a promontory of this continental margin (Göncüoglü *et al.* 1996–1997). Assuming

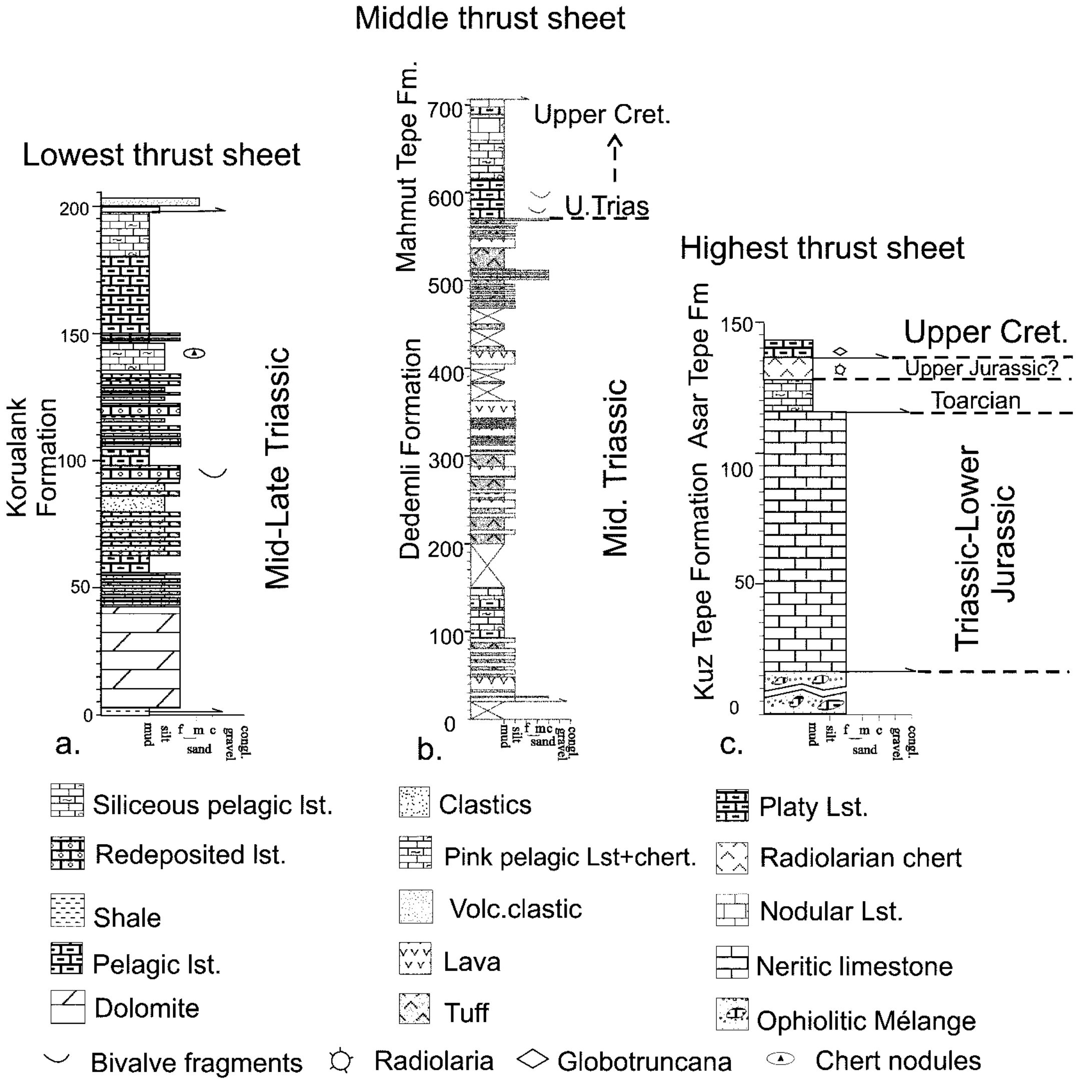

Fig. 8. Measured sedimentary logs of the Beyşehir–Hoyran units in the Bozkir area. (See Fig. 7 for location of logs.)

the in-sequence thrusting model (Fig. 16a), the conjugate of this margin is in the Pontides (Ustaömer & Robertson 1997; Yılmaz *et al*. 1997). The main problem is that the Pontide and Anatolide–Tauride margin evolution are dissimilar, e.g. with the major latest Triassic 'Cimmerian' orogenic event being restricted to the Pontide margin, whereas Triassic rifting and Jurassic passive margin subsidence continued on the Anatolide–Tauride margin without a comparable major orogenic event (Robertson & Pickett 2000). Assuming the out-of-sequence thrusting model, a rifted continental fragment would border the Anatolide–Tauride platform (Fig. 17b).

In Fig. 17b the Northern Neotethys was split into two branches, a main northerly oceanic strand and a southerly strand, termed the Inner Tauride Ocean, which split off a Kirşehir–Niğde microcontinent (Şengör & Yılmaz 1981; Görür *et al.* 1984). The Beyşehir–Hoyran upper thrust sheets again fringed the Anatolide–Tauride continental margin as in the out-of-sequence thrust model. The Beyşehir–Hoyran ophiolites formed at a spreading centre within the Inner Tauride Ocean. Assuming the in-sequence thrust model (Fig. 16b), the upper nappes could restore effectively as a westward extension of the Kirşehir–Niğde microcontinent (or satellite platforms).

Additional evidence from the Izmir–Ankara–Erzincan suture zone to the north of the study area is needed to test fully the concept of an Inner Tauride ocean (Okay *et al*. 2001). However, the extraordinary lateral continuity of the Beyşehir–Hoyran Nappes over *c*. 700 km, extending far to the SE of the Kirşehir–Niğde Massif, is consistent with the former existence of an Inner Tauride ocean, rather than requiring the nappes to be thrust >500 km from the Ankara–Erzincan suture zone north of the Kirşehir Massif.

We infer that the southern margin of the Northern Neoteothys was palaeogeographically irregular, with the Dinar units in the west being located in an embayment between the Geyik Dağ–Hadim platform to the east and the Menderes–Bey Dağları platform to the west. The Dinar units perhaps connected southward palaeogeographically through the Isparta Angle to the Southerly Neotethys (Robertson 1993).

In our favoured out-of-sequence thrust interpretation (Figs. 16b and 17b) the ophiolites were emplaced southwards along the length of the Anatolide–Tauride continental margin in latest Cretaceous (Campanian–Maastrichtian) time. Initial emplacement of a SSZ-type ophiolite onto the continental margin was followed by rethrusting of the accreted units and the ophiolite

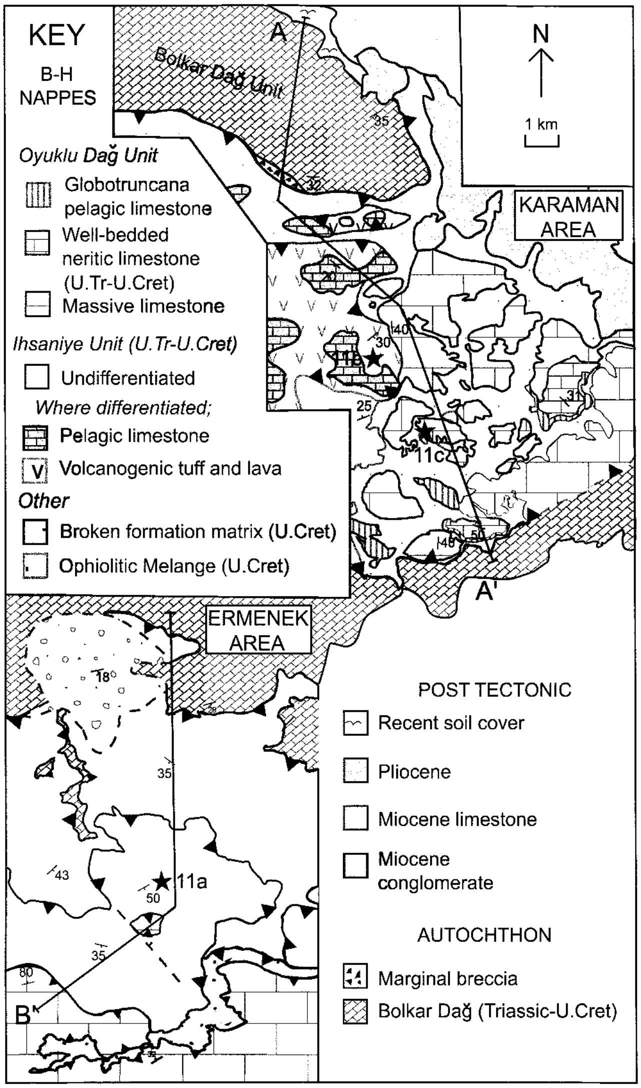

Fig. 9. Geological map of the Beyşehir–Hoyran Nappes in the Karaman–Ermenek area (modified from Koçyiğit 1976; Gökdeniz 1981).

during late Maastrichtian time. During Late Eocene time, related to suture tightening and regional final closure of the Northern Neotethys, the former carbonate platform edge was detached and thrust southwards as the Hadim Nappe and Bolkar Dağ Unit together with their cover of previously assembled allochthonous units. Further west, sited in a former palaeogeographical embayment, the Late Cretaceous Dinar thrust sheets were merely rethrust some distance further south over the relatively autochthonous carbonate platform without detaching large carbonate platform slices. The Late Eocene thrusting possibly relates to 'hard collision' that accompanied regional suturing of the Northern Neotethys. The presence of an Oligo-Miocene unconformable cover of the Dinar units shows that this deformation was soon over, whereas, by contrast, a similar southward rethrusting of the Lycian Nappes, beginning in Late Eocene time (Collins & Robertson 1998) was not completed until Late Miocene time (Poisson 1977).

Conclusions

Assuming our favoured out-of-sequence thrust model, we infer the following tectonostratigraphic events.

(1) The northern margin of Gondwana rifted in Triassic time, as represented by the autochthonous Taurus carbonate platform and the Hadim Nappe. Siliciclastic and carbonate turbidites accumulated in proximal slope settings (Korualan Group; Bozkir area). Bordering rift siliciclastic rocks and minor calc-turbidites (e.g lower Ihsaniye Unit, Ermenek area) were inundated with intermediate–silicic composition volcanic rocks, volcaniclastic rocks and tuff, which accumulated in a deep-water basin undergoing background radiolarian hemipelagic sedimentation. Neritic carbonate platforms developed in a generally more outboard setting (e.g. Boyali-Tepe Unit; Beyşehir area). Platforms and basinal units varied in scale and palaeogeographical location from west to east.

(2) Rifting ended in Late Triassic time and was followed by post-rift subsidence. Pelagic deposition persisted in rift basins (e.g. Huğlu Unit; Beyşehir area), whereas neritic platforms subsided in Early–Mid Jurassic time and were covered by calcareous pelagic sediments (including Ammonitico Rosso),

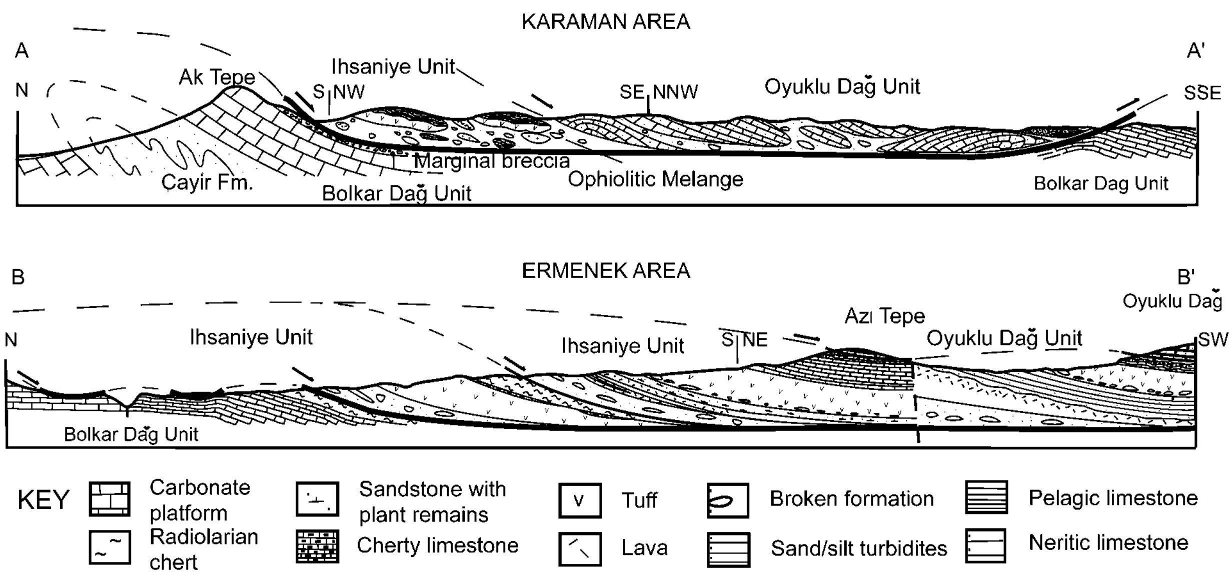

Fig. 10. Cross-section of the Beyşehir–Hoyran Nappes in the Karaman–Ermenek area.

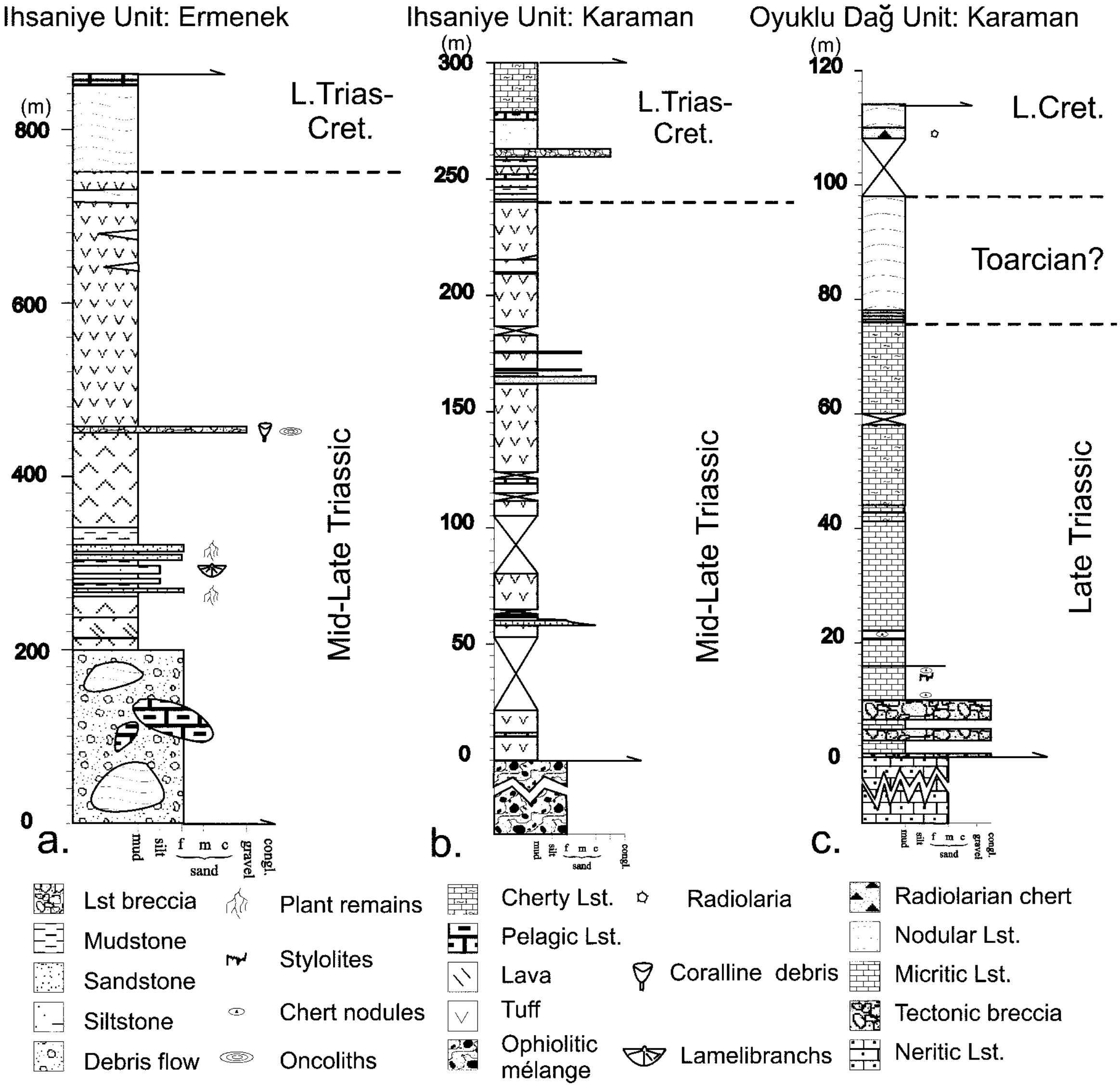

Fig. 11. Measured log of the Beyşehir–Hoyran units in the Karaman–Ermenek area. (See Fig. 9 for location of logs.)

above the CCD. Nodular radiolarian chert accumulated during Late Jurassic–Early Cretaceous time.

(3) The ophiolite was generated above a north-dipping intra-oceanic subduction zone probably in Late Cretaceous time. The amphibolite-facies metamorphic sole (Beyşehir area) was formed by underplating of oceanic crust beneath young hot supra-subduction zone lithosphere.

(4) The within-plate basalt and MORB-type volcanic blocks within the Ophiolitic Mélange, together with radiolarian chert, pelagic carbonates and volcanogenic sediments represent a Late Cretaceous subduction–accretionary complex related to northward subduction of Neotethys.

(5) Tectonic disruption of the higher Beyşehir–Hoyran Nappes within Late Cretaceous (Maastrichtian) ophiolite-derived matrix resulted from collision and accretion of the Tauride continental margin with the north-dipping subduction zone.

(6) During latest Cretaceous time the accretionary prism and SSZ ophiolite were emplaced southwards onto the northern edge of the Tauride carbonate platform (future Hadim Nappe), whereas platform deposition continued on the Tauride platform, *c.* 150 km further south.

(7) Erosion of the emplaced ophiolite probably took place in Paleocene times, although no trace of a cover sequence remains, unlike the Lycian Nappes.

(8) During Early Tertiary time any remaining Northern Neotethyan oceanic crust was subducted, leading to final collision of the Tauride continental unit with the Eurasian margin during Late Eocene time. During Late Eocene collision, the Palaeozoic–Early Tertiary successions were detatched as the Hadim Nappe and Bolkar Dağ Unit and were thrust up to 150 km southward over an Early–Mid-Eocene siliciclastic foredeep, with the previously assembled (Upper Cretaceous) nappe stack riding above. Further west (Dinar area), the regional platform remained *in situ* and the Upper Cretaceous Ophiolitic Mélange and ophiolite were thrust onto the Eocene siliciclastic foredeep, resulting in interlayering of mélange units of latest Cretaceous and Early Tertiary age.

(9) After collision, the Beyşehir–Hoyran Nappes underwent

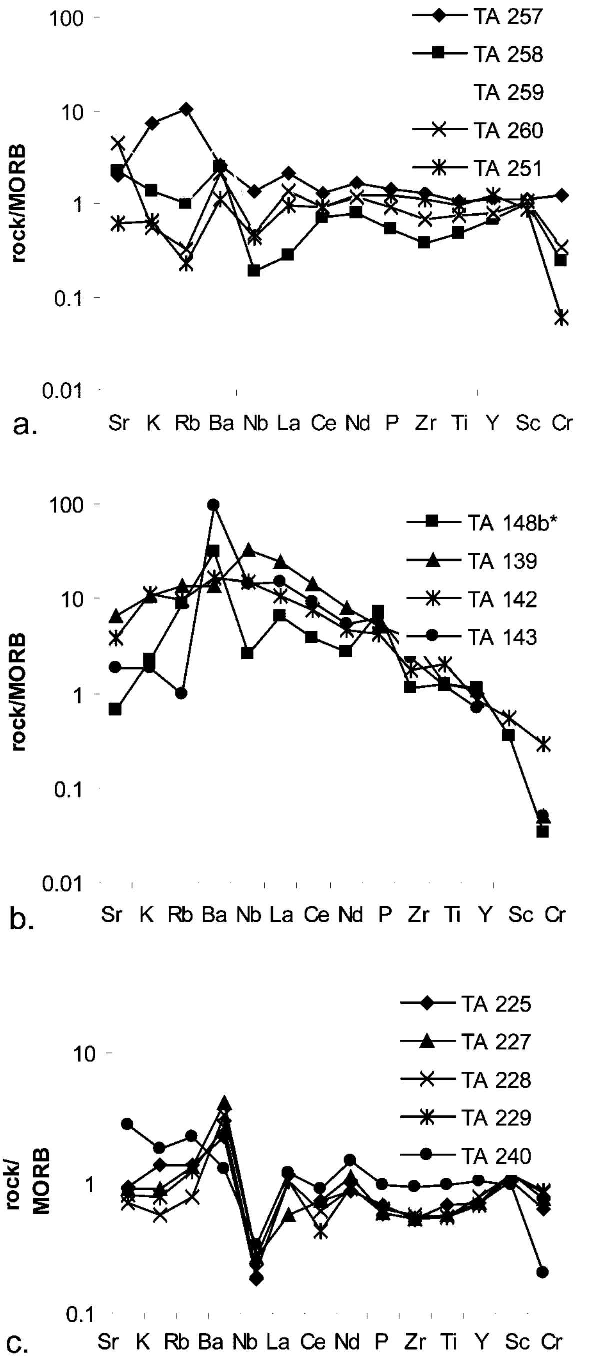

Fig. 12. Mid-ocean ridge basalt (MORB)-normalized incompatible element plots of selected basalt clasts within the Ophiolitic Mélange (normalizing values from Pearce 1983). (**a**) Dinar area; (**b**) Beyşehir area; (**c**) dolerite dykes cutting Kızıldağ ophiolite north of Lake Beyşehir (Şarkikaraağaç).

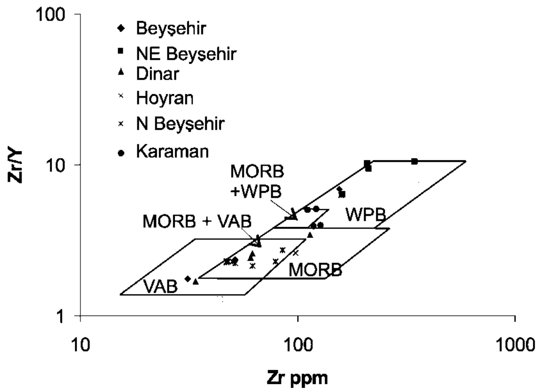

Fig. 13. Zr v. Zr/Y diagram (Pearce & Norry 1979) of selected basalt clasts within the Ophiolitic Mélange. MORB, mid-ocean ridge basalt; WPB, within-plate basalt; VAB, volcanic arc basalt.

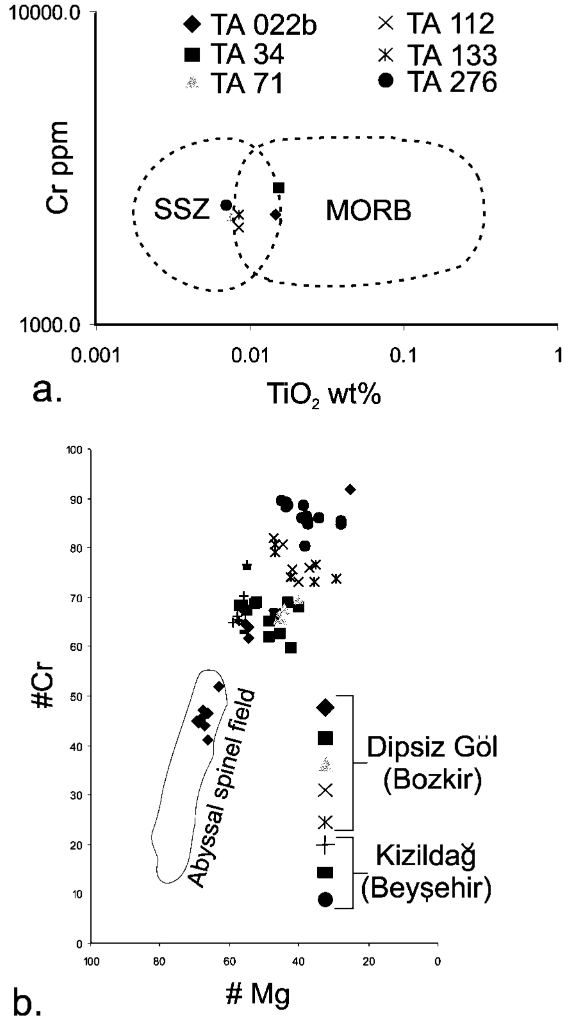

Fig. 14. (**a**) TiO_2 wt% v. Cr ppm whole-rock compositions of fresh peridotite from the Kızıldağ (Beyşehir) ophiolite (Pearce *et al.* 1984). (**b**) Chrome spinel compositions from peridotite of the Dipsiz Göl and Kızıldağ (Beyşehir) ophiolites, plotted on an Mg-number v. Cr-number diagram (Dick & Bullen 1984). Chrome spinels analysed on a Cameca Camebax electron microprobe at the University of Edinburgh, operated at a 20 kV accelerating potential and a beam current of 20 μm.

Miocene and younger extensional tectonics (e.g. east of Bozkir area–Dinar area) and clockwise palaeotectonic rotation.

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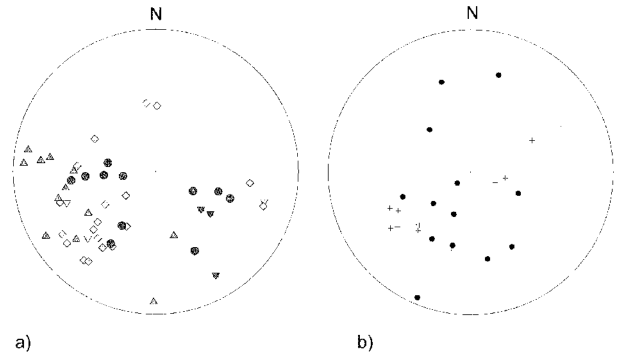

Fig. 15. (**a**) Equal-area lower hemisphere projection showing kinematic data from Beyşehir area. Down-facing triangles, poles to shear fabric (Derebucak); diamonds, slickenline lineations (Derebucak); up-facing triangles, fold data (throughout Beyşehir–Hoyran Nappes); circles, poles to shear fabric (Üzümlü); filled down-facing triangles, fold data (Üzümlü). (**b**) Equal-area lower hemisphere projection showing kinematic data from Ermenek area. Readings come from exposures throughout the thrust sheets. ●, fold data; +, slickenline lineations.

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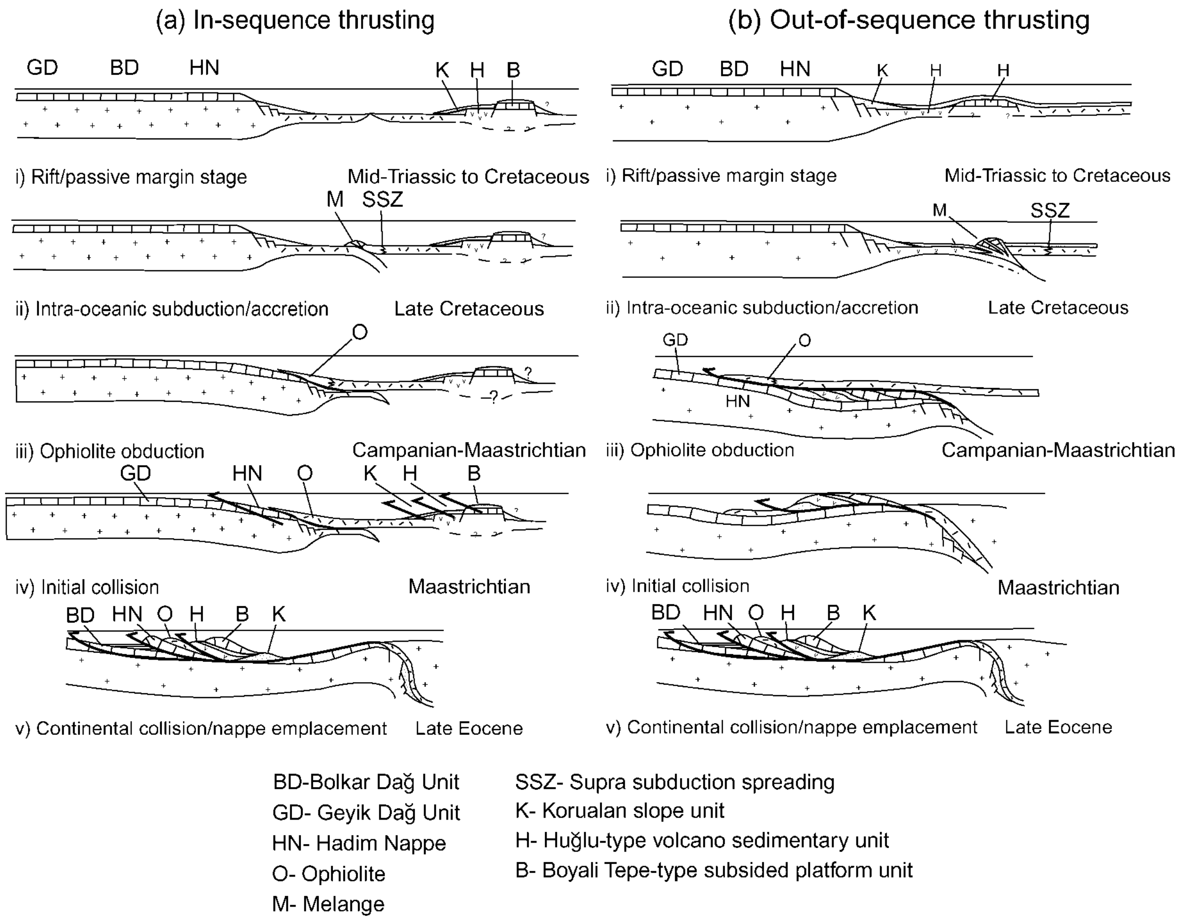

Fig. 16. Reconstructed tectonic settings assuming (**a**) in-sequence thrusting, (**b**) out-of-sequence thrusting. (**a**) Rifts separated the southern Tauride carbonate platform and off-margin fragment. After SSZ ophiolite genesis, the ophiolite and off-margin units were emplaced onto the continental margin in Maastrichtian time. During Late Eocene suturing and tightening the former platform margin was detatched and thrust southwards, carrying the previously assembled thrust stack passively above. (**b**) As (**a**), but the spreading centre developed northwards of the rifted carbonate platform. SSZ ophiolite genesis was followed by accretion of platform–basinal units beneath the overriding ophiolite, which was emplaced over the carbonate platform (Geyik Dağ). During collision the accreted units were rethrust above the ophiolite. Rethrusting in Late Eocene time occurred as in (**a**).

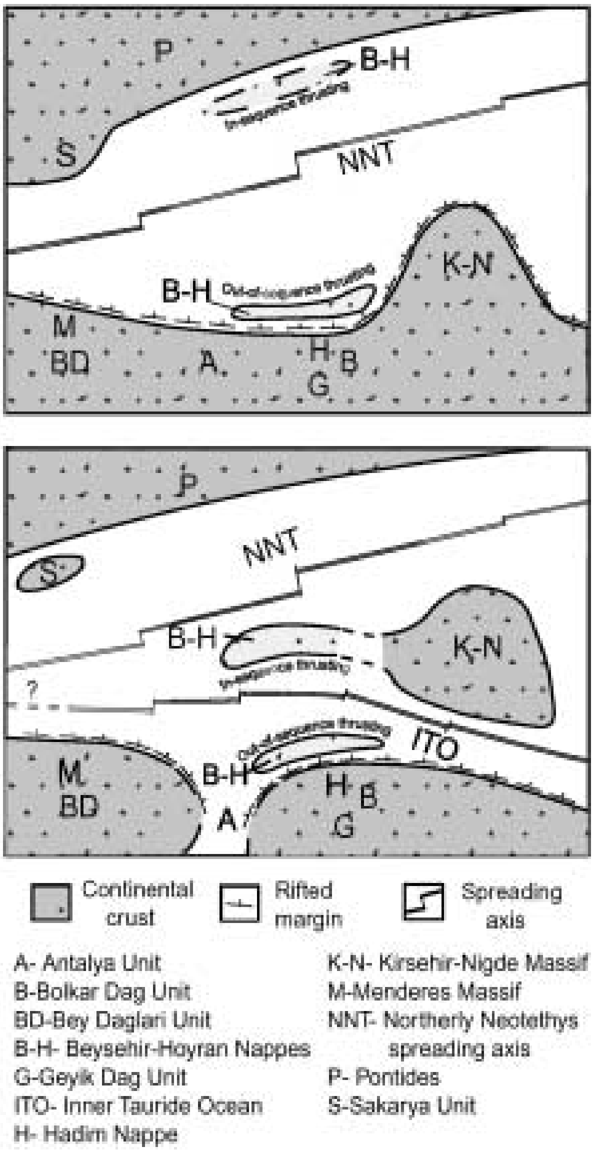

Fig. 17. Palaeogeographical sketch maps of the Northern Neotethys during Mid-Jurassic time. (**a**) Single Northern Neotethys with promontories. North and south alternative settings of the Beyşehir–Hoyran Nappes according to in-sequence or out-of-sequence thrusting (Fig. 16). (**b**) Northern Neotethys with microcontinents and again possible alternative settings of the Beyşehir–Hoyran Nappes. The model shown in (**b**) with southerly location of nappes is preferred. (Note, in (**b**), spreading possibly jumped northwards, isolating the Kirşehir–Niğde microcontinent from the Anatolide–Tauride platform.)

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